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(54) Method and apparatus for measuring defect density and defect distribution.

(57) A method and apparatus for measuring a defect distribution comprising introducing a narrowed laser beam into an object to be observed, receiving scattering lights generated at the defect portions of the object by a photoelectric conversion element, and measuring automatically the density and density distribution of the defects inside the object on the basis of the output image data of the photoelectric conversion element.

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METHOD AND APPARATUS FOR MEASURING DEFECT DENSITY AND DEFECT DISTRIBUTION

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a method and apparatus for automatically measuring the defect (or flaw) density and defect distribution inside an object without the destruction thereof by processing scattering light-derived image data obtained by a device for analyzing the object by use of scattering lights, the device having a function of precisely measuring the position of a sample of the object.

Description of the Prior Art

The defect density in a crystal has conventionally been measured by first etching the surface of the crystal and then observing through a microscope or measuring mechanically the recesses formed on the etched surface. (Refer, for example, to Jenkins, M. W.: "A New Preferential Etch for Defects in Single Crystals", J. Electrochem. Soc., 124:752-762, 1977.)

Further, X-ray diffraction is also an effective method of measuring the defect density (Refer, for example, to Jungbluth, E. D.: J. Electrochem. Soc., 112:580, 1965.), and this method has been used as an effective means of detecting the dislocation, stacking faults and precipitates in crystals. On the other hand, a transmission type electron microscope has been used to detect the dislocation and very fine precipitates inside crystals. (Refer, for example, to Meieran, E. S.: Appl. Phys., 36: 2544, 1965.)

Furthermore, as a method of analyzing an object by use of scattering lights, Japanese Patent Laid-Open No. 109488/1979 (corresponding to U.S.P. No. 4,411,525) discloses a method of analyzing the internal structure of an object along a desired cross-section, which method comprises the steps of causing a light beam transmitting through a desired cross-section of an object to be analyzed, causing the object to move in a direction intersecting with the direction of the light beam so that the plane including the light beam becomes the desired cross-section, creating scattering lights which carry information of the internal structure along the path of the light beam transmitting through the object to scan along the cross-section, consecutively observing the scattering lights along an optical axis intersecting with the cross-section, and consecutively recording the observed scattering lights on a recording medium which is moved in synchronization with the scanning of the light beam, whereby the internal structure of the object is analyzed along the cross-section by summing all the information of the scattering lights obtained by the scanning of the light beam.

Etching is currently used most widely in the process of measuring the distribution of defects in the internal structure of an object. However, it is intended for two-dimentional (superficial) observation of the defects that are distributed three-dimensionally in crystals and the measurement is not sufficient in accuracy. Etching may involve the use of toxic chemicals (hydrofluoric acid, hexavalent chromium, etc.) and the evolution of toxic gases, and, thus, it is a dangerous operation. Furthermore, because of being a destructive inspection method, the etching method is defective in that the crystal that has once been treated cannot be used for further measurements such as observation of a change in defects in the crystal after repeated annealing thereof.

An X-ray diffraction method is an effective means of measuring the defect density and can detect the dislocation and stacking faults. However, it can hardly detect small defects such as very fine precipitates inside silicon. It cannot be used for the observation of the interior of the crystal three-dimensionally, either. In the same way as the etching method, the X-ray diffraction method is not entirely safe because of exposure to X-rays.

An transmission type electron microscope can detect the dislocation and very fine precipitates in crystals with a sufficiently high level of sensitivity, but raises a problem in that the crystal must be sliced in a thickness of several thousand angstroms thereby to limit the microscope in its usability for measurement. In addition, this method using the electron microscope is not an expedient one since it needs a large-sized and complicated apparatus.

Furthermore, in accordance with conventional methods of analyzing an object by use of scattering lights, it has not been possible to automatically measure the defect density and defect distribution. Another problem with this method is that the defect distribution and the number of defects must inconveniently be measured and counted manually from pictures, e.g. photographs, obtained.

SUMMARY OF THE INVENTION

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In view of the problems with the prior art technique described above, the present invention has for its object to provide a method and apparatus for measuring the defect distribution in a crystal, which satisfy all the following requirements when measuring the defect density and defect distribution in an object such as a crystal:

(1) The method and apparatus can effect the measurement without destruction of the crystal;

(2) They can observe the object three-dimensionally;

(3) They are respectively highly safe ones;

(4) They are expedient to practise or operate; and

(5) They can automatically measure quantitatively the defect distribution.

The object of the present invention may be achieved by providing a method of measuring the defect distribution, which is characterized in that a narrowed laser beam is radiated to an object to be observed, scattering lights generated from the laser beam at the defect portions inside the object are received by a television camera or the like to obtain picture or image information, and the defect density as well as defect distribution inside the object is automatically measured or found from the image information.

The defect distribution measuring method of the present invention comprises radiating a narrowed laser beam into an object to be observed, receiving scattering lights generated from the laser beam at the defect portions inside the object, and measuring or finding the DZ (Denuded Zone) width of the object from a one-dimensional distribution of the scattering intensities of the scattering lights.

Furthermore, in accordance with the present invention, there is provided an apparatus for measuring the defect distribution which comprises a means for radiating a narrowed laser beam to an object to be observed, a means for obtaining image information from the scattering lights generated from the laser beam at the defect portions in the object, and a means for automatically measuring or finding the defect density and defect distribution in the object from the image information.

In the method and apparatus for measuring the defect distribution in accordance with the present invention, a narrowed laser beam is radiated into an object to be observed, scattering lights from the defect portions of the object are received by a photoelectric conversion element such as a television camera, and the defect density is measured on the basis of the output image data of the photoelectric conversion element.

More particularly, a narrowed laser beam is radiated to a crystal (object), scattering lights from the defect portions of the crystal are received by a television camera or the like, its output is subjected to A/D (analog-to-digital) conversion by an image processor and its image data are stored in the memory device of a computer. These procedures can be carried out while scanning the laser beam or moving a sample stage, to obtain image data of defects on one section of the object. The number of defects is found from the image data by an image processor having a processing function of binary image data. Since the number of defects thus found corresponds to the number of defects inside the laser beam diameter, the defect density per unit volume can be determined by dividing the number of defects per unit area of the image by the laser beam diameter.

The laser beam source to be used here must emit a laser beam having a wavelength that transmits through the object crystal. If the object is Si or GaAs crystal, it is effective to use a YAG laser having a wavelength of 1.064 micron meter. The photoelectric conversion element used here must be able to detect this laser beam. A CCD (Charge-Coupled Device) and a silicon vidicon are effective for the YAG laser.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing one embodiment of apparatus for measuring automatically a defect density by scattering light in accordance with the present invention;

Fig. 2 is a schematic view showing the defect image in a Si crystal and the defect density distribution in the direction of depth from the surface of the Si crystal;

Fig. 3(a) is a photograph showing a crystal structure as a scattering light image inside the Si crystal, the image being obtained by a scattering light method;

Fig. 3(b) is a diagram showing the scattering intensity distribution in the Si crystal;

Fig. 4 is a schematic view showing the defect image in the Si crystal and the defect density distribution in the direction of depth from the surface;

Fig. 5 is an exemplary diagram showing the defect density distribution obtained by the scattering light image;

Fig. 6 is a schematic view showing how to obtain a tomogram image (scattering light image);

Fig. 7 is a flow chart showing a sequence of procedures for the measurement of a DZ width and a defect density distribution;

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Fig. 8 is a structural view of the principal portions of an automatic measuring apparatus for receiving scattering lights from defects in a crystal by a line sensor and pulsing them to obtain the defect density distribution in the crystal;

Fig. 9 is a diagram showing the scattering intensity per defect particle;

Fig. 10 is a diagram showing the average diameter of precipitates; and

Fig. 11 is a diagram showing the total volume of precipitates.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Example

An Example of the present invention will hereinafter be described with reference to the accompanying drawings.

Fig. 1 is a block diagram showing the construction of an apparatus of automatically measuring the defect density in an object by use of a method of analyzing the object by use of scattering lights in accordance with one embodiment of the present invention. In the drawing, reference numeral 1 represents a sample (object to be observed) whose defect distribution is to be measured; 2 is a laser generator for generating a laser beam to be radiated to the sample 1; 3 is a microscope equipped with an autofocus mechanism; 4 is a television camera for converting received scattering lights to electrical signals; and 5 is an image processor for receiving the electrical signals from the television camera and making image-processing. This image processor 5 has a function of processing binary image data. Reference numeral 6 represents a CRT (Cathode-Ray Tube) for outputting the image data as they are or defect density values, etc., obtained as a result of various calculations; 7 is a computer for controlling the system as a whole when measurement is made; 8 is a pulse motor controller; 9 is an X - Y - Z pulse stage which is driven in X-, Y-, Z-directions in accordance with the instruction of the pulse motor controller 8; and 10 is a precise sample position detector for detecting precisely the position of the sample 1.

Hereinafter, measurement of the distribution of very small defects inside an Si wafer by use of the present apparatus will be described.

In the manufacture of semiconductor elements, the defect density distribution and DZ (Denuded Zone) width of a Si wafer are usually measured. They are measured with the apparatus shown in Fig. 1 by carrying out image-processing of scattering images obtained by said light scattering method.

Reference numeral 11 in Fig. 2 represents schematically scattering light images which are obtained by placing a half-cleaved Si wafer as the sample 1 on the pulse stage 9 in the apparatus shown in Fig. 1, radiating a laser beam to the Si wafer and observing scattering light images through the microscope 3 from the cleavage plane side of the Si wafer. Reference numerals 101 and 102 represent the crystal surfaces of the Si wafer, and reference numerals 103 and 104 represent small defects having various sizes inside the Si wafer. The distribution of the defects (precipitates) along the depth from the surface of the crystal, which distribution is represented by reference numeral 12 in Fig. 2, can be known on the basis of such scattering light images. Reference numeral 105 represents a width, or so-called "DZ width", from the crystal surface 101 to a depth at which the defect density exceeds a predetermined value. The measurement of this DZ width is carried out by any one of the following two methods: (1) a method for measuring the DZ width on the basis of the distribution of scattering intensity in the direction of depth from the crystal surface (the distribution being one-dimensional distribution), and (2) a method of measuring the defect density in a unit volume along the depth from the crystal surface by conducting image processing on the basis of the scattering light image data.

In said measuring method (1), the accurate position of the surface of the Si wafer (sample 1) must be known. Therefore, the position of the wafer surface is adjusted or monitored by use of the precise sample position detector 10 shown in Fig. 1. This is carried out by allowing the computer 7 to input position data from the precise sample position detector 10 and driving the X - Y - Z pulse stage 9 by the pulse motor controller 8 on the basis of this input. Next, the position of the sample stage 9 in the Z direction (perpendicular to the sheet of drawing) is adjusted by the auto-focus mechanism of the microscope 3 in order to always keep constant the position relation from the cleavage plane (the observation plane by the microscope 3) to the position at which the laser beam is incident. The sample 1 is then moved for scanning to obtain scattering light images.

Fig. 3(a) shows scattering light images thus obtained, and is a photograph showing the crystal structure of the Si wafer. The intensity distribution in the direction of depth of the crystal is obtained from scattering light images as shown in Fig. 3(b). This Fig. 3(b) is a diagram representing the intensity distribution on line L - L' of the scattering light images obtained in Fig. 3(a). On the basis of such an intensity distribution, the DZ width 105 is de-

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fined as the distance from the surface of the crystal to the position at which the scattering intensity is a predetermined value. In this Example, the predetermined value is set to be 30% of the average scattering intensity inside the crystal, but, in place of this value, an appropriate other value can be set separately. Since the scattering intensity distribution changes greatly from position to position at which measurement is made, the DZ width is measured at several positions and the values obtained are averaged to obtain a suitable DZ width.

Next, the method of measuring the defect density distribution by conducting image processing on the basis of the scattering light image data will be described. Among the scattering light image data, there are those which indicate various defects (precipitates) having different scattering intensities as shown in Fig. 4(a). Therefore, the scattering intensity of each pixel of the image data is digitized by a predetermined threshold value to obtain binary image data such as shown in Fig. 4(b). The data are then subjected to contraction processing (refer, for example, to Hideyuki Tamura, "Introduction To Computer Image Processing", Soken Shuppan, p. 80) in order to separate one by one the precipitates (defects) as shown in Fig. 4(c). The predetermined threshold value is such that it can remove noise of the television camera 4 and the defect density to be measured will be the maximum one.

Then, as represented by dash lines shown in Fig. 4(c), a window for counting the defect density having a sufficiently smaller width than the DZ width is set in the binary image data subjected to the contraction processing. The number of defects is counted while moving this window so as to obtain the distribution diagrams (see the diagram 12 in Fig. 2) of the defect density from the front surface to the back of the wafer. The DZ width is defined as the depth from the crystal surface to the position at which the defect density reaches a predetermined value. In this embodiment, this predetermined value is set such that the defect density is 30% of the average defect density inside the crystal, but an appropriate other value can be set separately, besides the predetermined value described above.

Fig. 5 is a diagram showing a defect density distribution obtained by the scattering light images.

Further, if two or more kinds of scattering bodies (defects) exist, the kinds are judged by changing the threshold value described above or effecting pattern recognition of the scattering bodies (refer to the aforementioned reference "Introduction To Computer Image Processing", page 85) in order to measure the density distribution and DZ width of each of the kinds of scattering bodies as shown in Fig. 2.

Fig. 6 is a schematic view showing how the tomogram images (scattering light images) are obtained.

The procedures for obtaining the defect density distribution such as represented by reference numeral 12 in Fig. 2 will hereinafter be explained with reference to the flow chart of Fig. 7.

First of all, the sample 1 to be measured is placed on the X - Y - Z pulse stage 9 in the step S1. The sample 1 is then moved to the observation position in the step S2, and the place of incidence of the laser beam as well as the observation plane by the microscope 3 is adjusted to each of predetermined positions. The pulse stage 9 is driven in the step S3 to move the sample 1 for scanning and to obtain scattering light images. Thereafter, if there is employed a measuring method based on the distribution of scattering intensity in the direction of depth from the surface of the crystal, the flow proceeds to the step S7, and if there is employed a method of obtaining the defect density distribution by image processing on the basis of the scattering light image data, the flow proceeds to the step S4.

The digitization processing dascribed above is made for the image data by the scattering lights in the step S4, and contraction processing is further carried out in the step S5. The defect density distribution and the DZ width are obtained in the step S6.

On the other hand, the DZ width is found from the one-dimensional distribution of the scattering intensity in the step S7.

The measurement is thus completed.

Fig. 8 shows the essential components of an alternative apparatus for automatically measuring the defect density distribution according to the invention.

In the apparatus shown in the drawing, the laser beam 31 is radiated into the sample 32 as the object to be observed, and the scattering lights from the defects are received by a one-dimensional photoelectric detector such as a line sensor 34 or two-dimensional photoelectric detector through an object lens 33. The sample 32 is moved for scanning in the direction represented by arrow to obtain an electrical output at each position of the line sensor 34. If any defects pass through the laser beam flux, the scattering lights from the defects are incident into the line sensor 34 to generate pluses. Therefore, the electrical output at each position is stored in a date buffer 35 and the pulse at each point is counted by a pulse counter 36. In this manner, the distribution of the defect density of the sample 32 can be determined.

The objects to be observed may be single-crystal oxides, single-crystal semiconductors, glass such as optical fibers and other material through

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which the laser beam can pass.

According to the present invention, it is possible to measure the defect density (n) and the scattering intensity (I) of the scattering light from the defect portions inside a crystal. The scattering intensity (I) is expressed by the following formula.
The scattering intensity (I) = the number of the defects (n)
x the scattering intensity per defect particle (i)
Therefore, it is possible to compute the scattering intensity per defect particle (i). Fig. 9 is a diagram showing the scattering intensity per defect particle as a function of distance (or depth) from the surface of a crystal.

Further, when the defect particle is small in size as compared with the wavelength of the light impinging upon the crystal, the scattering intensity per defect particle (i) is proportioned to the square of the volume of the defect particle.

The scattering intensity per defect particle (i) is
α (the volume of the particle (v))^2 and
α (the radius of the particle (d))^6.
Therefore, it is possible to compute the volume of the particle (v) and the radius of the particle (d) on the assumption that the particle is spherical. Fig. 10 is a diagram showing an average diameter of precipitates (defect particles) as a function of distance from the surface of the crystal.

Furthermore, the total volume of precipitates is expressed by the following formula:
The total volume of precipitates (V).
= The volume of unit defect particle (v)
X the number of the defect particles (n)
Therefore, it is also possible to compute the total volume of precipitates (V). Fig. 11 is a diagram showing the total volume of precipitates as a function of depth from the surface of the crystal.

As described above, the present invention renders it possible to make image-processing of the images formed due to the scattering lights and determine the defect distribution in the object to be observed. Therefore, the invention enables the defects in the object to be observed three-dimensionally without the destruction of the object. Furthermore, the present invention neither require toxic liquids nor produce toxic gases unlike the etching method and is therefore highly safe. Since the present invention makes it possible to measure the defects of an object without the destruction thereof, the change of the defects which may be caused by repeatedly annealing the object can be observed and measured.

Measurement of very small defects inside the Si crystal is very important from the viewpoint of device process, and the present invention which is highly safe, non-destructive and highly reliable is extremely effective for such measurement. In addition, when the measurement is made, pre-treatment such as etching of the object to be observed is not necessary and a conventional visually measuring time for which several minutes of time has been necessary per unit area observation by eyes can now be reduced to several seconds according to the present invention.

Claims

1. A method of measuring a defect density and defect distribution comprising:
introducing a narrowed laser beam into an object to be observed;
receiving scattering lights obtained as image data when the laser beam falls on the defect portions inside said object; and
measuring the density and density distribution of the defects inside said object on the basis of said image data.

2. A method of measuring a defect distribution comprising:
introducing a narrowed laser beam into an object to be observed;
receiving scattering lights generated when the laser beam falls on the defect portions inside said object; and
measuring a DZ (Denuded Zone) width of said object on the basis of the one-dimensional distribution of scattering intensity of the scattering lights.

3. An apparatus for measuring a defect distribution comprising:
a means for introducing a narrowed laser beam into an object to be observed;
a means for receiving scattering lights generated at the defect portions of said object as image data; and
a means for measuring the density and density distribution of the defects inside said object on the basis of said image data.

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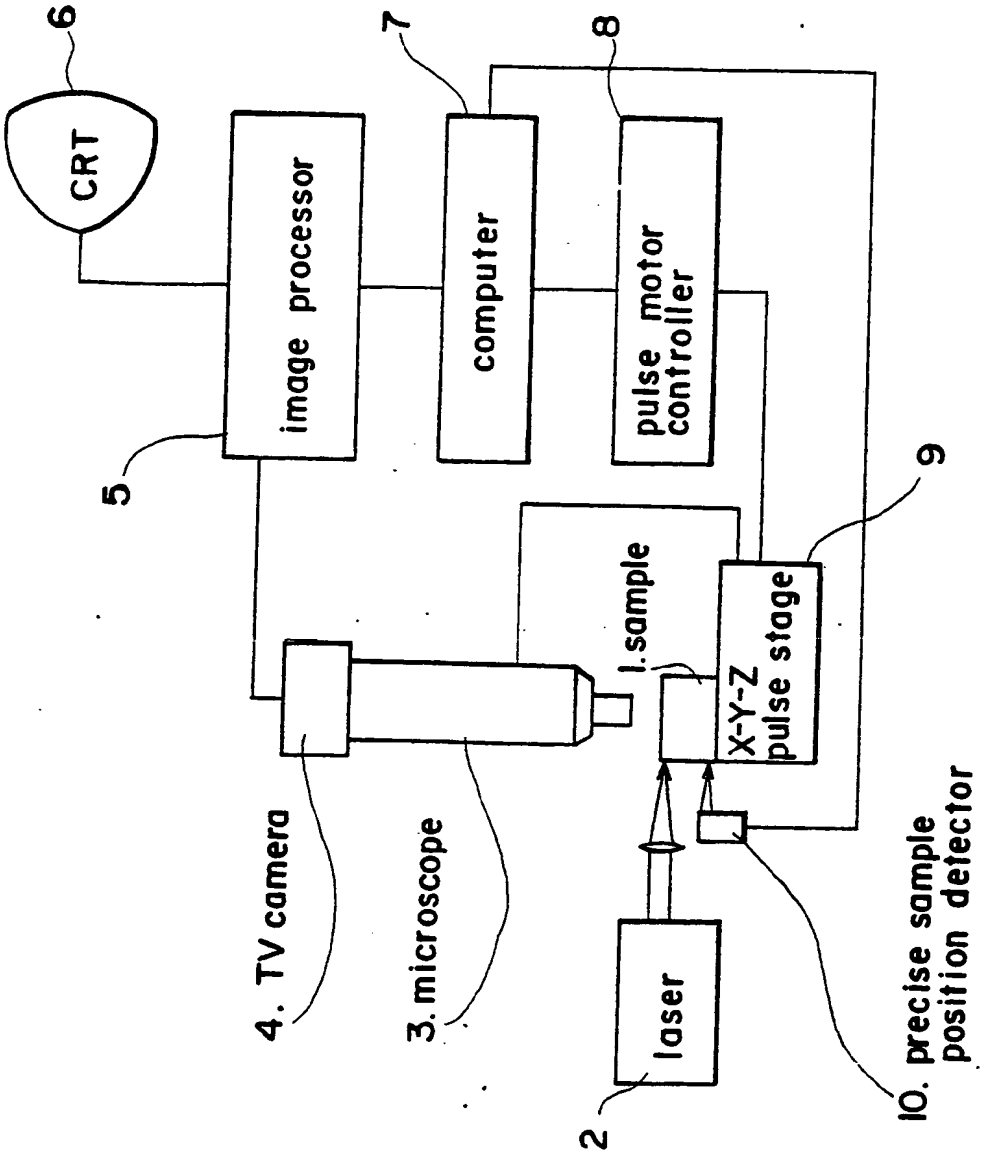

6
CRT
7
8
image processor
computer
pulse motor controller
5
9
1. sample
X-Y-Z pulse stage
4. TV camera
3. microscope
laser
2
10. precise sample position detector

FIG. 1

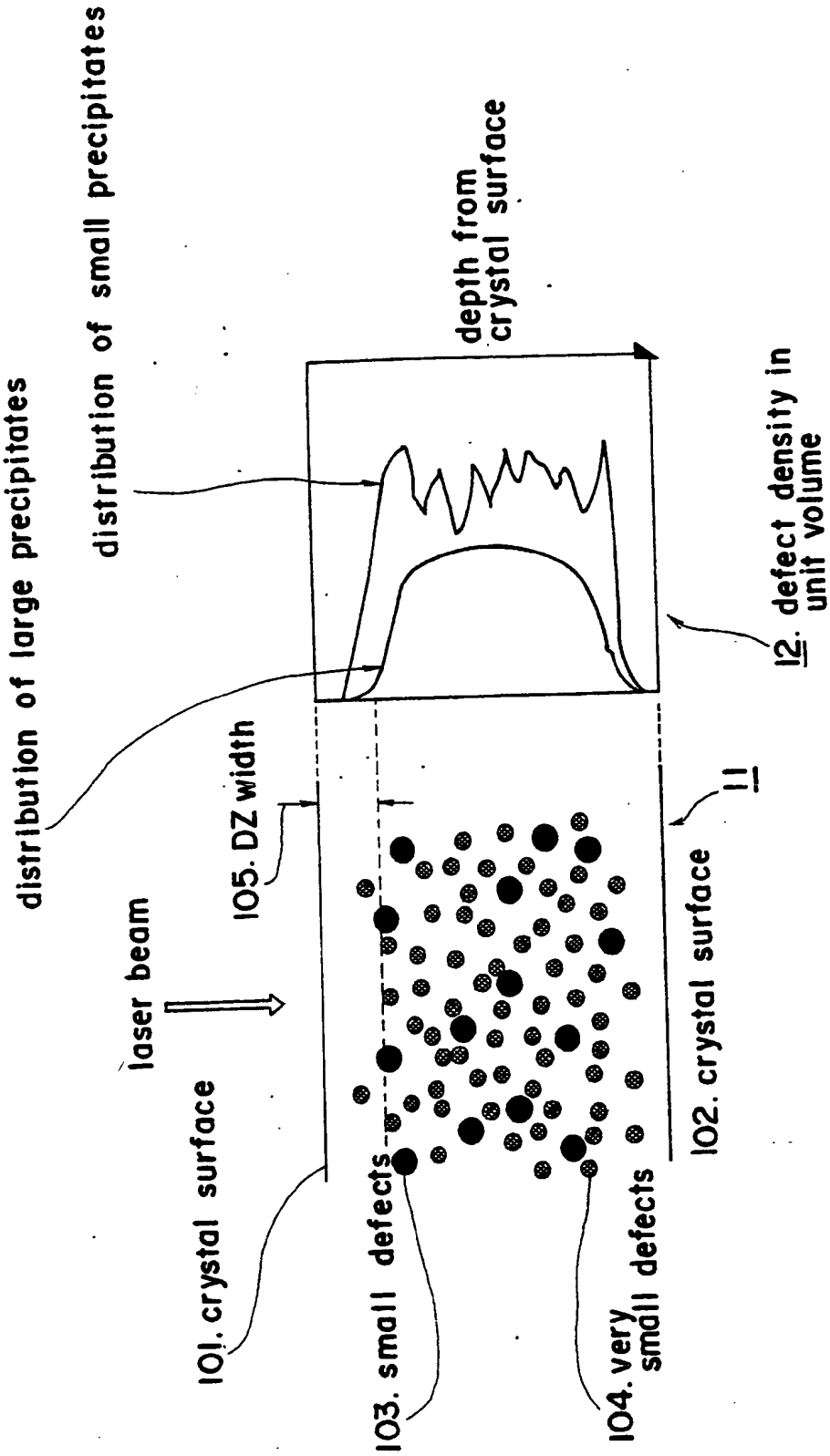
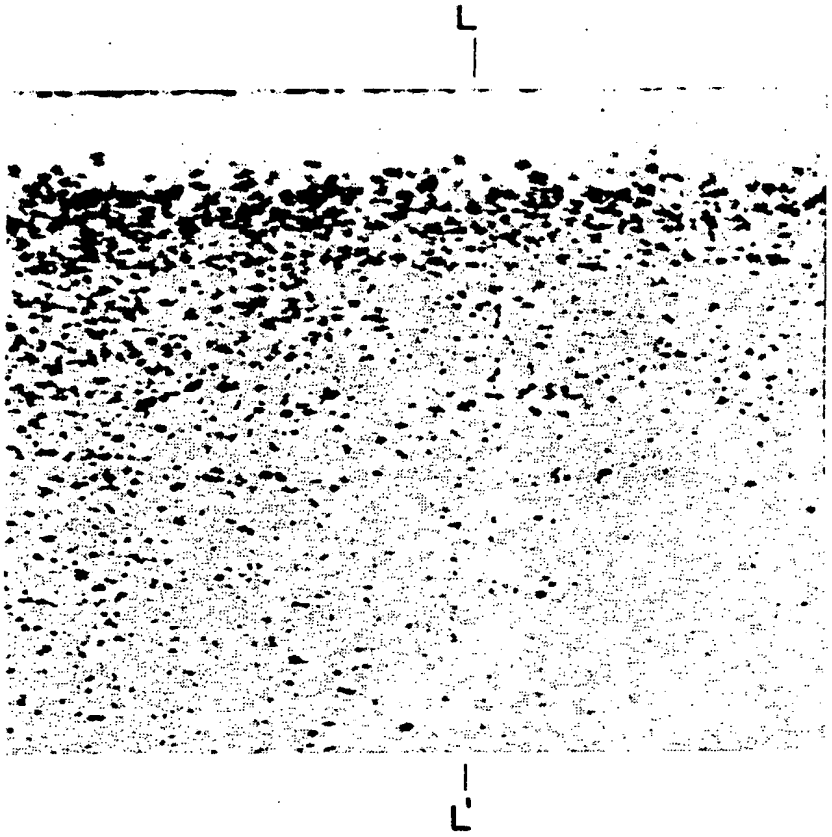
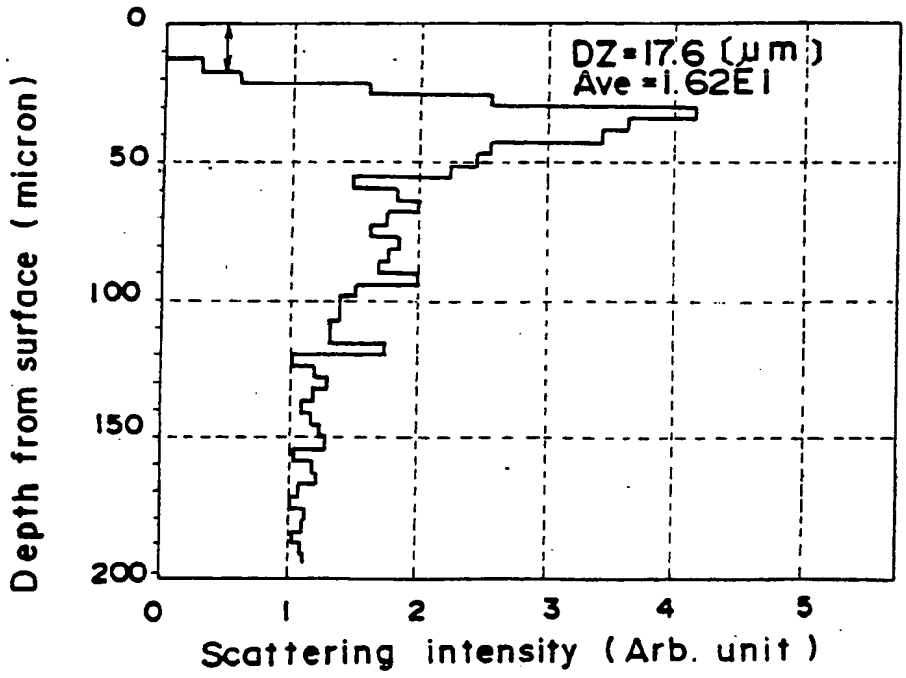

distribution of large precipitates
distribution of small precipitates
depth from crystal surface
12. defect density in unit volume
laser beam
105. DZ width
11
101. crystal surface
103. small defects
104. very small defects
102. crystal surface

FIG. 2



(a) Scattering light image (laser tomogram)



(b) Distribution of scattering light imag intensity
(distribution on line L - L')

FIG. 3

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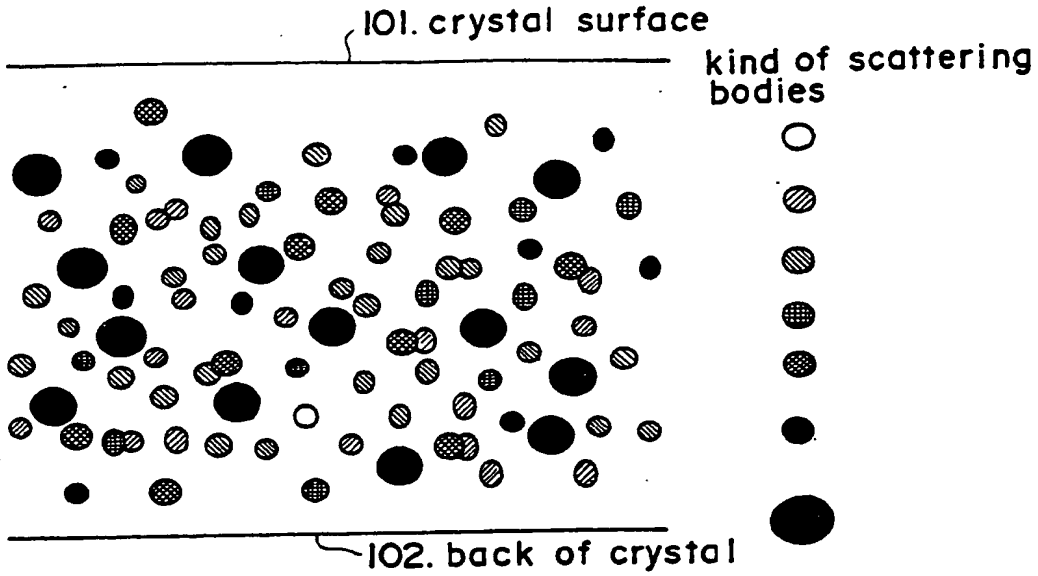
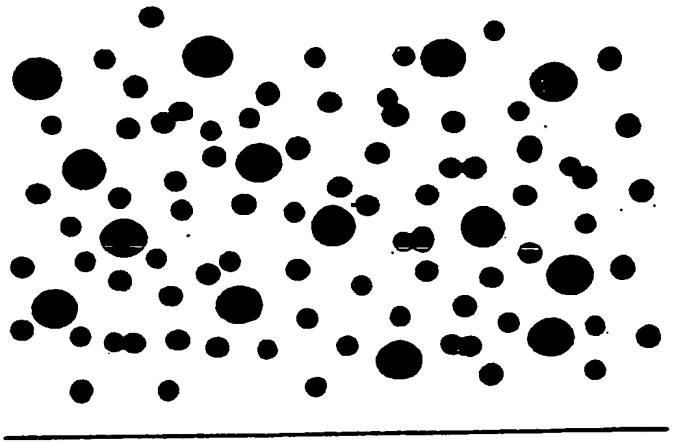
(a) Scattering light image



(b) Digitization processing



(c) Contraction processing

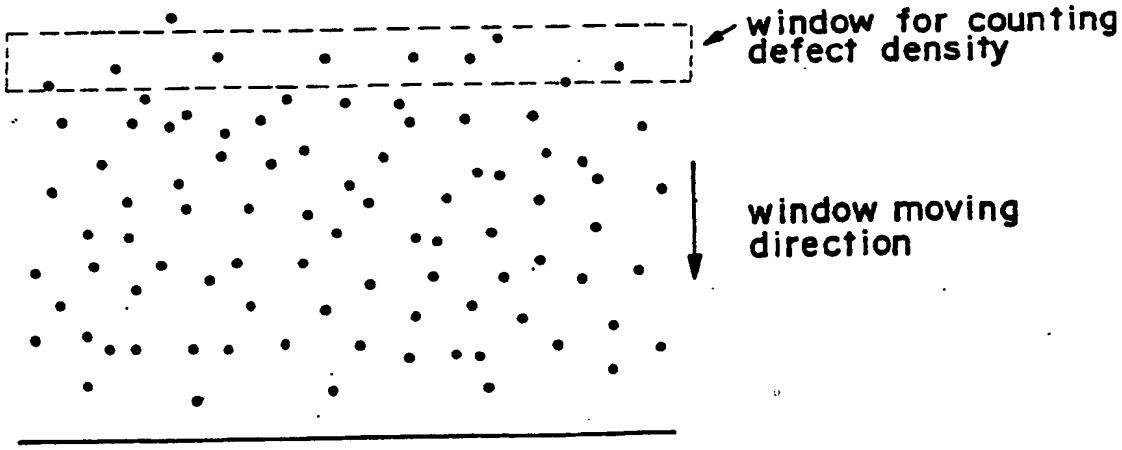


FIG. 4

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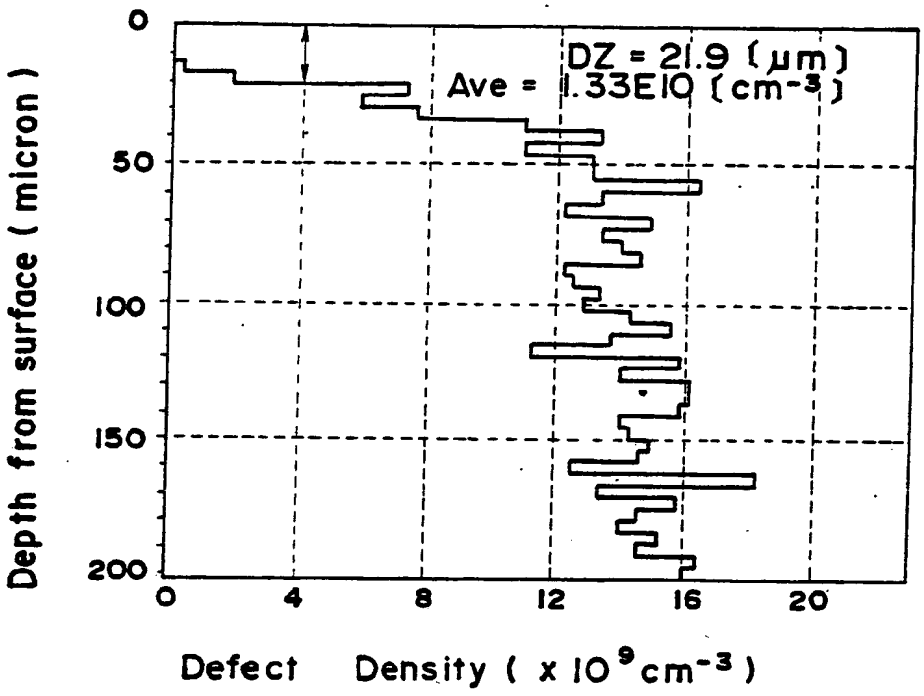

FIG. 5

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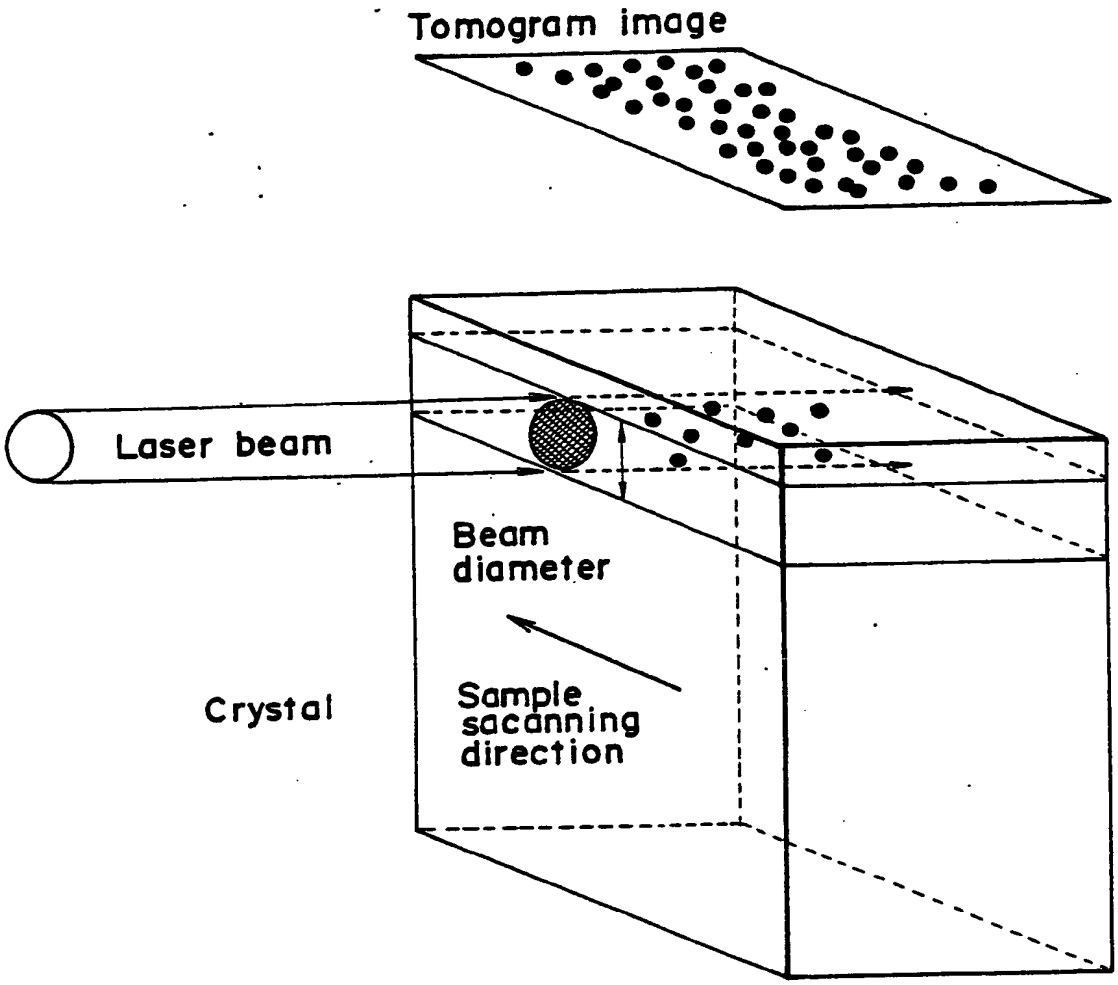
Tomogram image
Laser beam
Beam diameter
Crystal
Sample sacanning direction

FIG. 6

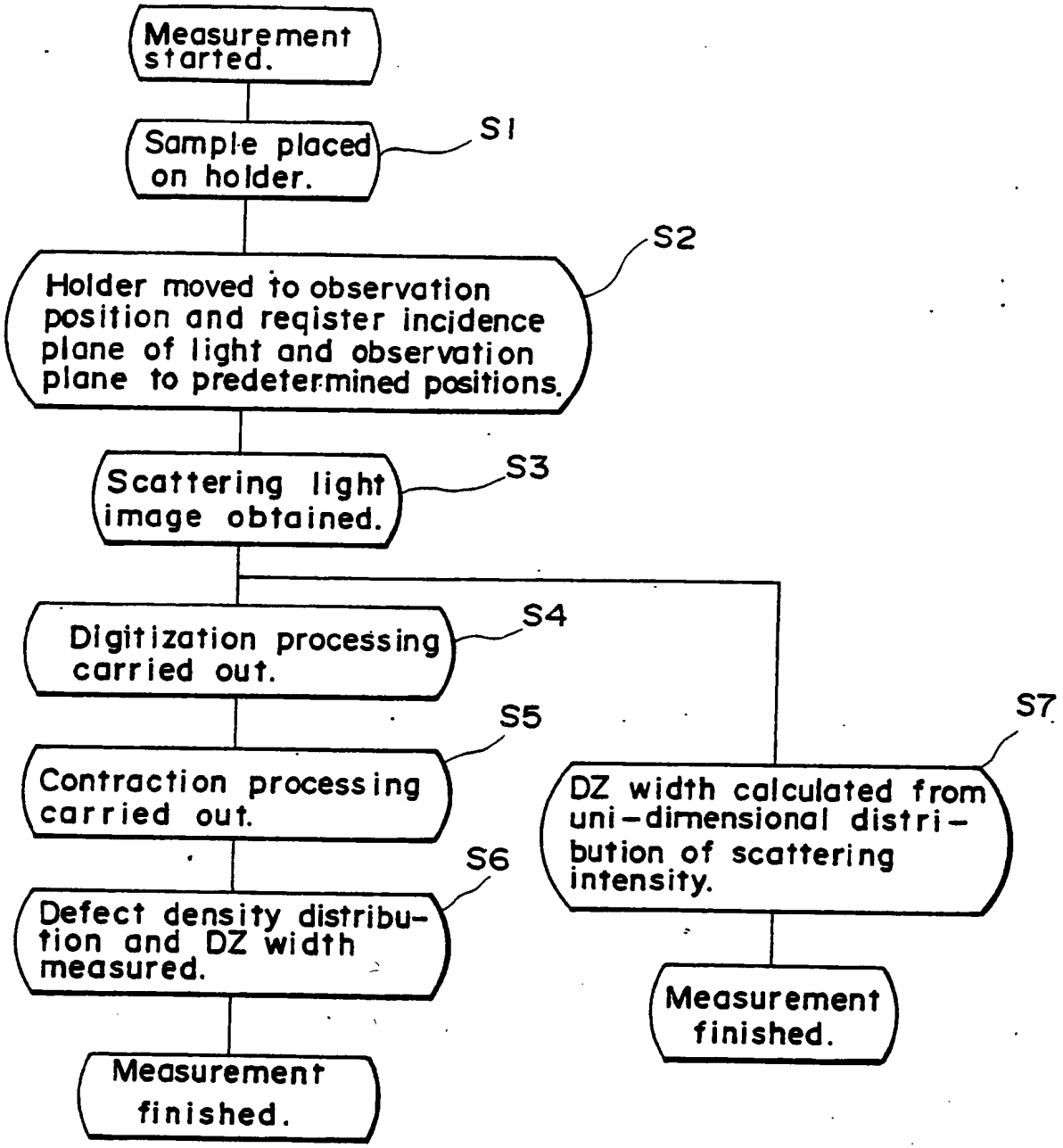

FIG. 7

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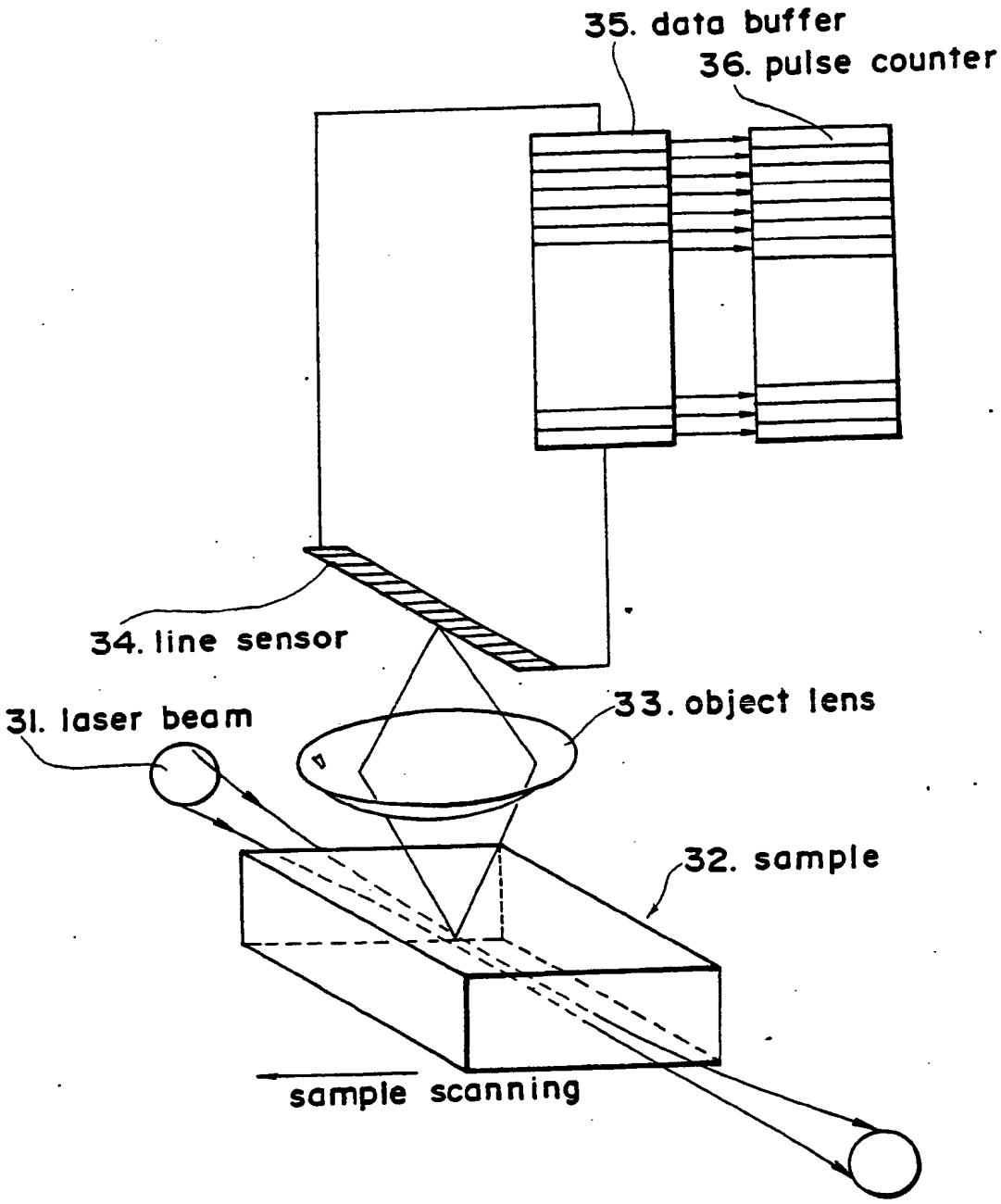
35. data buffer
36. pulse counter
34. line sensor
31. laser beam
33. object lens
32. sample
sample scanning

FIG. 8

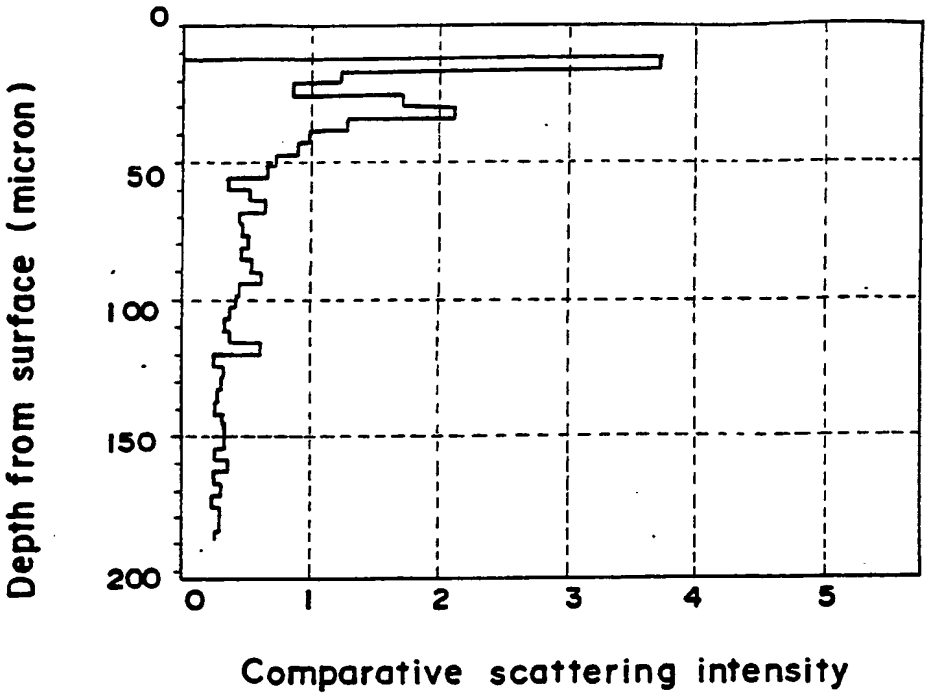
Depth from surface (micron)
0
50
100
150
200
0
1
2
3
4
5
Comparative scattering intensity

FIG. 9

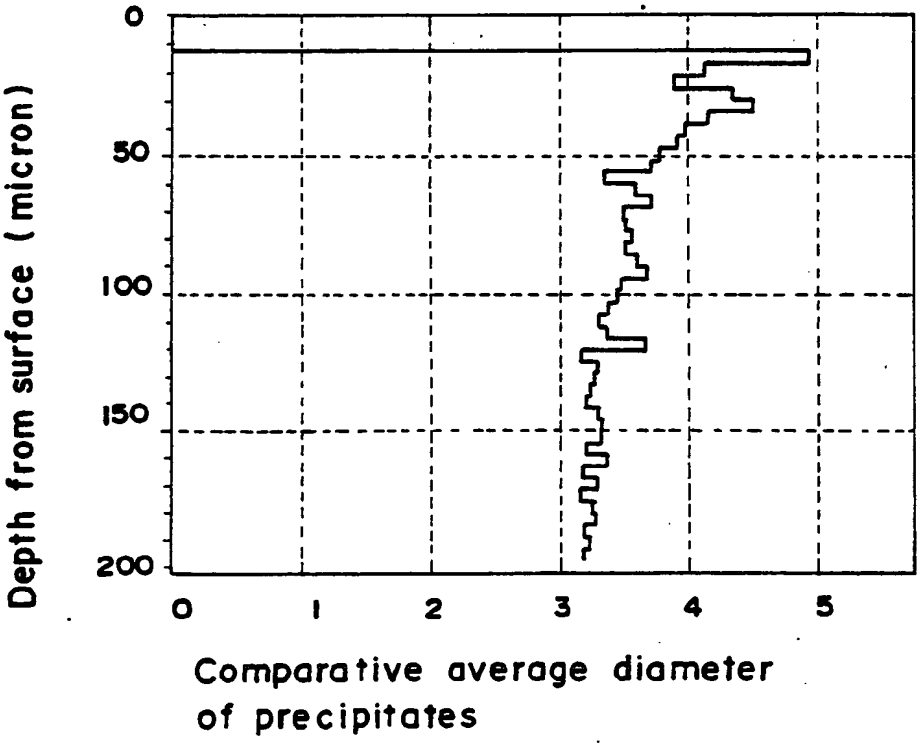
Depth from surface (micron)
0
50
100
150
200
0
1
2
3
4
5
Comparative average diameter of precipitates

FIG. 10

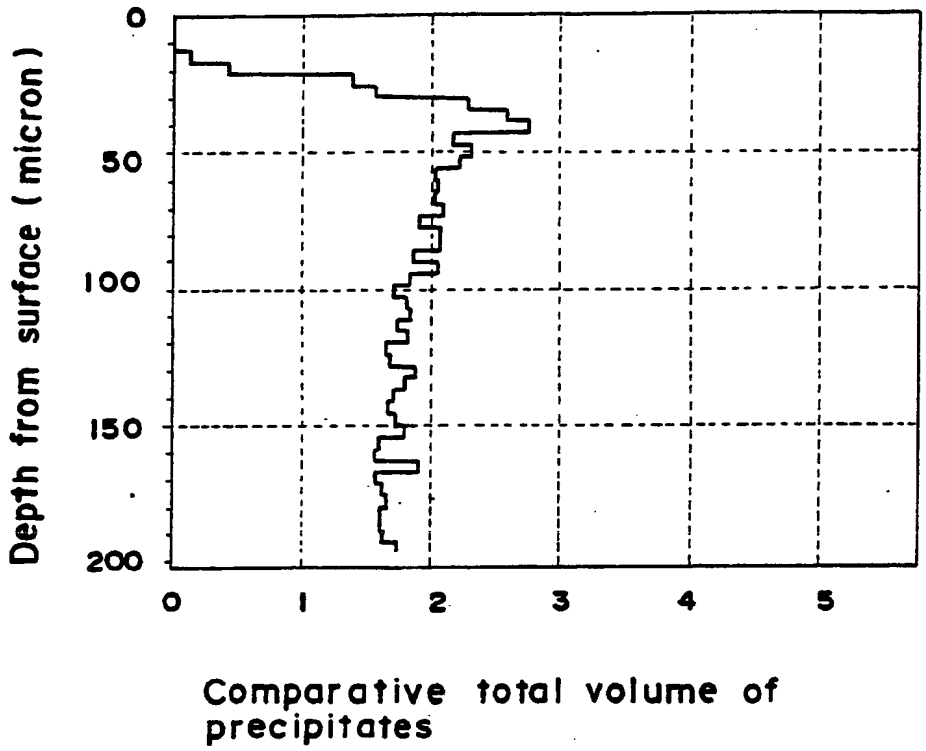
Depth from surface (micron)
0
50
100
150
200
0
1
2
3
4
5
Comparative total volume of precipitates

FIG. 11

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(54) Method and apparatus for measuring defect density and defect distribution.

(57) A method and apparatus for measuring a defect distribution comprising introducing a narrowed laser beam into an object to be observed, receiving scattering lights generated at the defect portions of the object by a photoelectric conversion element, and measuring automatically the density and density distribution of the defects inside the object on the basis of the output image data of the photoelectric conversion element.

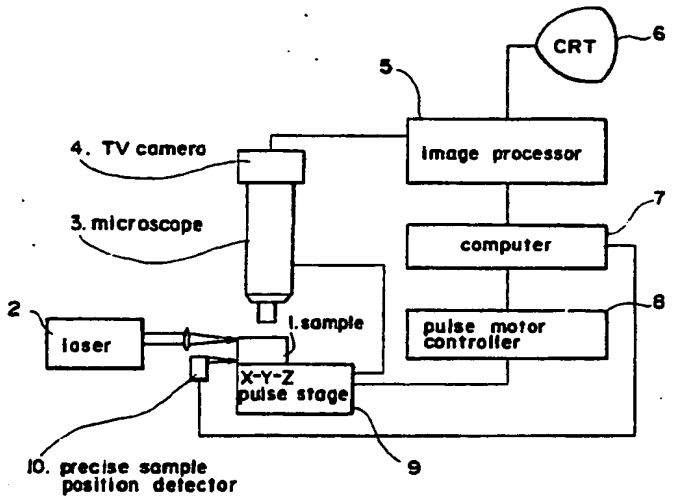

FIG. 1

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EUROPEAN SEARCH REPORT

Application Number

EP 88 11 9684

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	JAPANESE JOURNAL OF APPLIED PHYSICS vol. 22, no. 4, April 1983, Part 2, pages L207-L209, Tokyo, Japan; K. MORIYA et al.: "Abservation of Lattice Defects in GaAs and Heat-treated Si Crystals by Infrared Light Scattering Tomography" * whole document * ---	1-3	G 01 N 21/88 G 06 F 15/70
X	JAPANESE JOURNAL OF APPLIED PHYSICS LETTERS vol. 26, no. 8, August 1987, Part 2, pages L1255-L1257, Tokyo, Japan; J.P. FILLARD et al.: "Defect Structures in InP Crystals by Laser Scanning Tomogrphy" * figure 1 * ---	3	
X	PATENT ABSTRACTS OF JAPAN vol. 11, no. 42 (P-545)(2489), 6 February 1987; & JP - A - 61 213 651 (MITSUI MINING & SMELTING CO. LTD.) 22.09.1986 ---	3	
A,D	US-A-4 411 525 (T. OGAWA) * whole document * ---	1-3	TECHNICAL FIELDS SEARCHED (Int. Cl.4) G 01 N G 06 F H 01 L
A	JOURNAL OF APPLIED PHYSICS vol. 62, no. 9, 1 November 1987, pages 3700-3703, New York, NY, USA; P. SUCHET et al.: "Evidence of the origin of infrared scattering in GaAs with high-resolution infrared tomography". * figure 1 * -----	3	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	05-03-1990	BRISON O.P.

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